ESTIMATING AXLE LOADINGS ON STATE HIGHWAYS IN INDIANA

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by

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To: G. A. Leonards, Director
Joint Highway Research Project

September 24, 1965

From: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-54FF
File: 3-3-32

The attached technical paper "Estimating Axle Loadings on State Highways in Indiana" has been prepared by Roy Larson and William Grecco of our staff. It was presented at the 1965 Annual Purdue Road School and is scheduled to be included in the Proceedings of that School.

The paper is a brief summary of the research report "Procedural Guide for Estimating Axle Loadings on a Statewide Basis" which was presented to the Board at an earlier date.

The paper is presented to the Board for the record and for approval of publication.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Secretary

HLM:bc

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Technical Paper

ESTIMATING AXLE LOADINGS ON STATE HIGHWAYS IN INDIANA

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Project No: C-36-54F7
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Purdue University

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Estimating Axle Loadings on State Highways in Indiana

Introduction

The state highway departments are charged with the responsibility of providing adequate facilities to meet the demands of motor vehicle transportation. In order to accomplish this assignment, a system must be designed which will consider traffic volumes, the types and weights of vehicles, and the frequency of load application as system loadings. Considerable emphasis by the Bureau of Public Roads and the various state highway departments has provided the highway planners with acceptable procedures for establishing traffic volumes on rural and urban highway systems. Equally important from the design standpoint is the magnitude and frequency of load application made on the roadway pavement.

In the United States, all trucks represent only about sixteen percent of the total registered motor vehicle population. (1)* Including both private and for-hire trucks, in 1964 there were over fourteen million trucks registered and of these, only 35 percent contributed to the design consideration of the structural pavement. An even smaller percentage or approximately eight percent have axle loads which are significantly of concern. The structural design of pavements is dependent upon the weights of a relatively small number of the total motor vehicle population. It should be pointed out, however, that these heavier vehicles are more fully utilized and operated many more

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*Numbers in parenthesis refer to references listed at end of paper.

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miles per year. These two important facts make statistical weight estimates more acceptable than if there were many different trucks operated over shorter distances per year.

Truck Trends

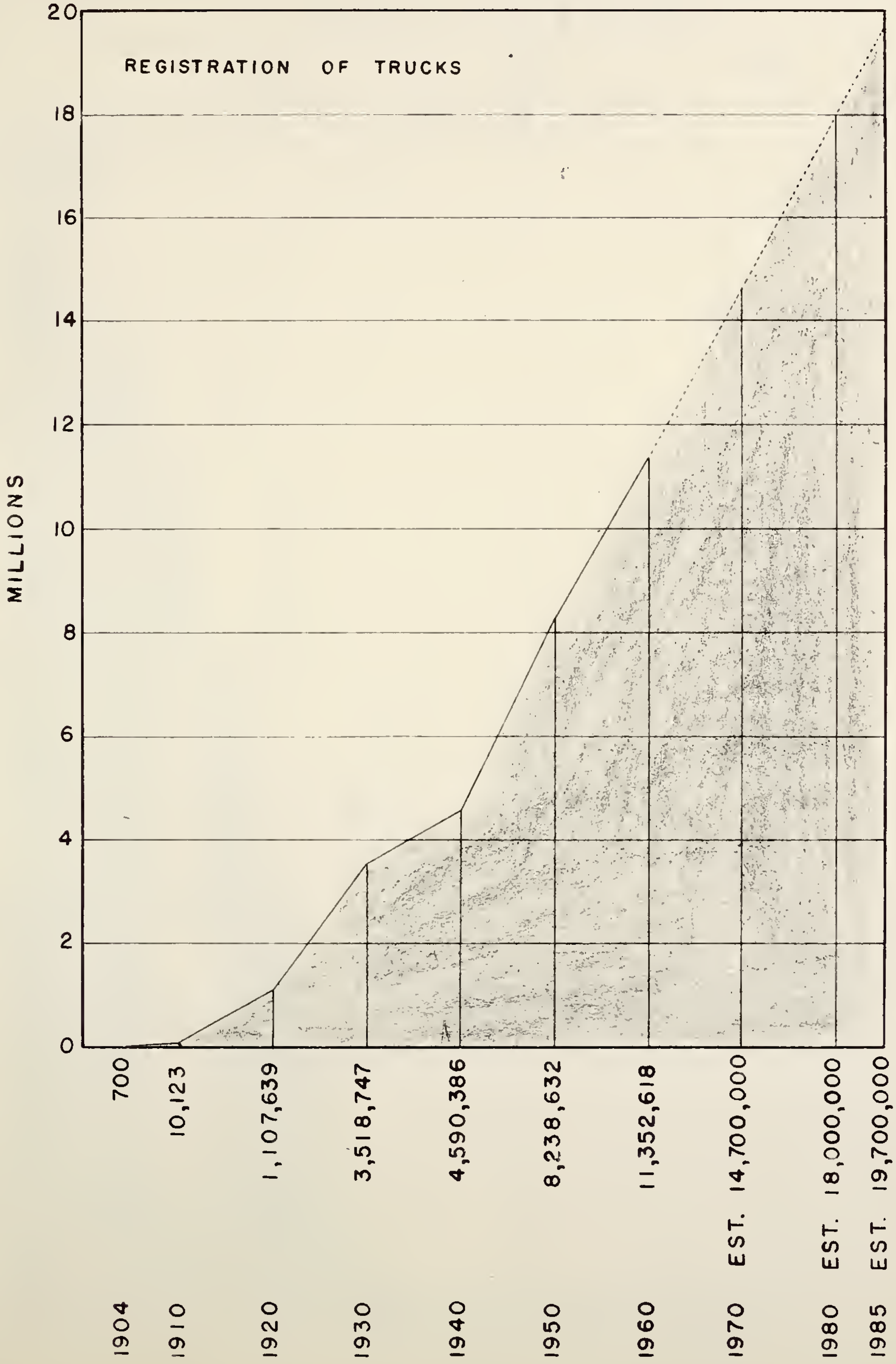
Also important to the future design of structural pavements are the trends of truck weights and their numbers. Since the introduction of the motor vehicle, the number of trucks and the amount of goods moved by trucks have increased greatly. As shown in Figure 1, the number of trucks registered in the United States has increased substantially from [illegible] until [illegible] and since that time the increase has been rapid. The over 14 million trucks registered in the United States in [illegible] represented approximately 40 percent of the world's total trucks. (2)

Truck travel in [illegible] reached 91 billion miles over main rural and local roads and 49 billion miles over urban streets. The total of 140 billion truck miles in and between cities represents an increase of [illegible] billion miles over the previous year and was triple the 1939 truck mileage. These facts are shown in Figure 2. (1) The total of 140 billion miles represent 17 percent of the total vehicle miles traveled in [illegible].

The movement of goods by truck has shown a parallel increase with truck registration and vehicle miles. In [illegible], the first year that intercity ton-miles of freight for trucks were recorded, trucks were

FIG. 1 GROWTH IN TRUCK USE IN THE UNITED STATES

REFERENCE (3)



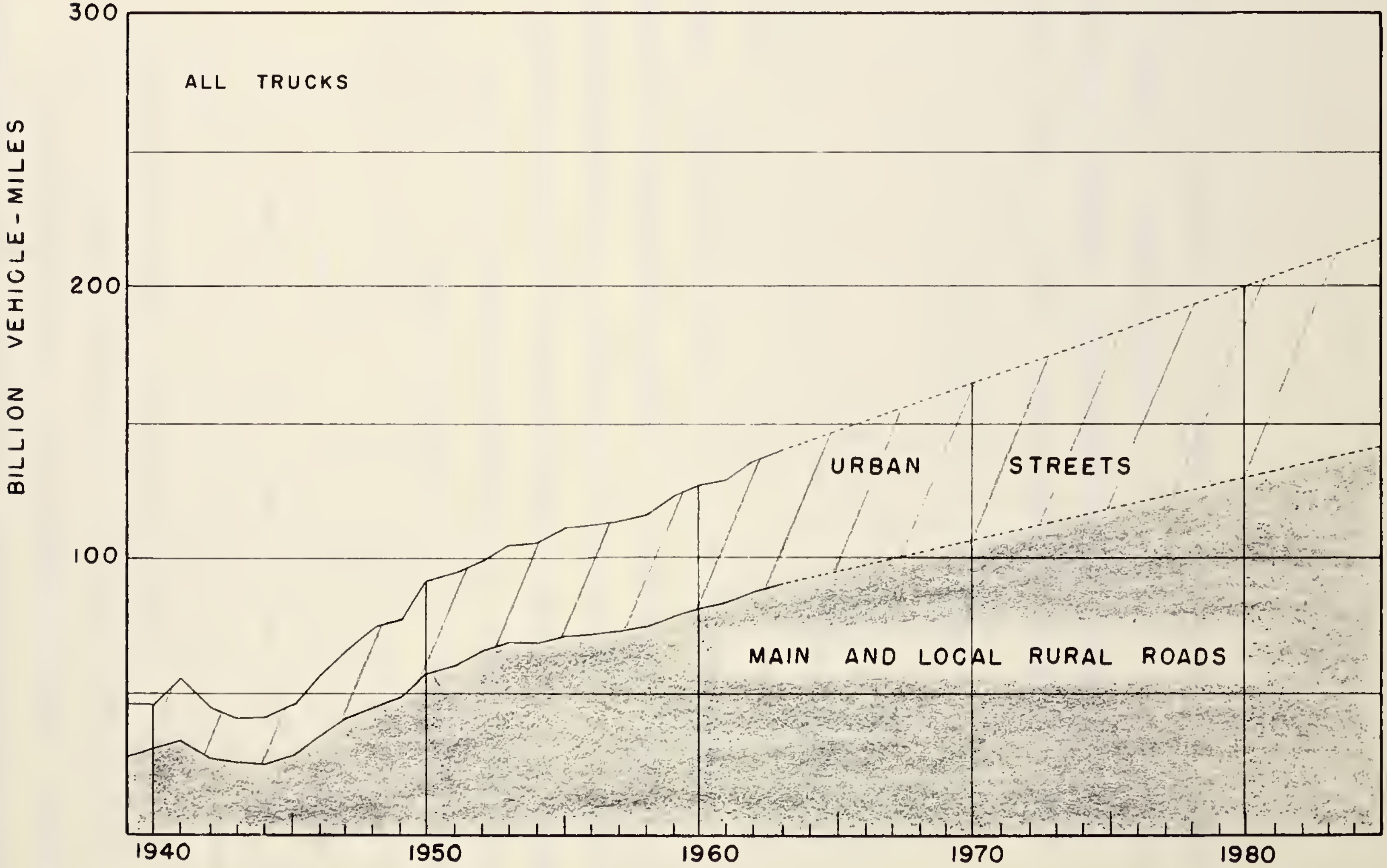


FIG. 2 TRUCK VEHICLE MILES

REFERENCE (1)

credited with 53 billion ton-miles. In 1963, trucks were credited with 347.9 billion ton-miles or 23.8 percent of the total ton-miles carried by intercity freight carriers. This represents a 101 percent increase in the rate of growth since 1950. (1)

Trucking is big business in Indiana. The trucking industry represents the largest single source of employment, creating jobs for 248,209 people and an annual payroll of 1.2 million dollars. In Indianapolis alone, there are over 100 common carrier lines serving the city and at least twelve major freight lines maintain headquarters there. In the state, 86.8 percent of all outbound freight is handled by trucks. Of the 858 post offices in the state of Indiana, 654 or 77 percent receive and send all their mail by motor transport. A total of 1,580 or 49.6 percent of the Indiana communities depend entirely on trucks for all freight transportation. In addition over 90,000 farm trucks are engaged in hauling agricultural products from Indiana farms. With the increase in industries and in research and development programs, the motor truck will become an increasingly important part of the state's economy.

Truck Loads and Applications

Because of the increasing volume of intercity freight transported by commercial highway vehicles, an estimate of the number of axle load applications and truck volumes on a specific section of a highway is needed by highway engineers, planners, and administrators. This information

is essential for the determination of design standards, for the systematic classification of highways, and for the development of programs for improvements and maintenance. In addition, the number of axle load applications and total truck volumes are important for the development of highway financing and taxation schedules and for the measurement of the service provided by highway transportation.

One general approach to the problem of estimation is to establish the boundary conditions and then to proceed from one limit toward the other until the requisites, set by the purpose of the analysis, are met. For this example the extreme conditions are:

1. to establish by a small sample, the average weight of all vehicles classed as trucks and to assume the average percentage of trucks in the traffic stream on the state highway system. These two factors would provide a most economical estimate of axle loadings,
2. to establish a program which would measure weights of all vehicles on all sections of the state highway system each day of the year. The estimate here might not be considered as such since it would contain the whole population of trucks.

As we map the two extremes, we find that condition one, though most economical, can not provide a valid estimate for design purposes

while condition two provides an accuracy beyond the requirements and at a prohibitive cost. The solutions lie between these two points and whether one moves from one toward two or in reverse depends upon the over-riding constraint. In the proposed estimation, cost was assumed to be the limiting factor with an accuracy subject only to statistical testing at the 95 percent confidence level. In an effort to keep costs near the present loadometer budget in the state, time was sacrificed and an estimation program for Indiana would not be operational for a period of four to five years.

Procedure

The basis for the procedure is the research finding that many of the presently operated loadometer stations weigh vehicles of each class which do not on the average differ by weight from those weighed at other stations. If these similarities can pass certain statistical tests then one station can operate for the other (slave station) with only a classification being made at the slave station.

The procedure developed in this research for estimating axle loadings on a statewide basis provides for the following steps:

1. The highways of the state be classified by system; Interstate, Federal Aid Primary, Federal Aid Secondary and Federal Aid Urban. This assumes weight differences by system. The roads in each of the four systems are to be divided into sections of varying length to provide at least one location within the section suitable for conducting the loadometer operation

and to provide relatively constant weight distribution throughout the section. See Figure 3.

2. For each section operated the first year (Indiana will probably continue to have 22 stations), the following information will be established: ADT, percent cars, percent trucks, the number of each truck type and the axle weights. Weighing will be done on the basis of Bureau of Public Roads Memorandum (4). Probability sampling on the basis of ten minute intervals should be used at locations where the volumes are so great that all passing trucks cannot be weighed. See Figure 4.
3. For each truck type, the axle weights and condition (loaded or unloaded) are recorded for each vehicle weighed. Each axle load is converted to an equivalent 18 kip single axle load and then summed to give an equivalent 18 kip axle load for each truck that is loaded. A similar procedure is followed for each unloaded truck. See Figure 5.
4. The first test for similarity is to check by highway system if the average 18 kip equivalent weights of all truck types are statistically equal for all stations. This test is performed by a two way Analysis of Variance. Since the above test requires equal variances in all cells, a test of Homogenity of Variance must precede it. On occasion, homogenity can be achieved through proper transformation of the data. See Figure 6.

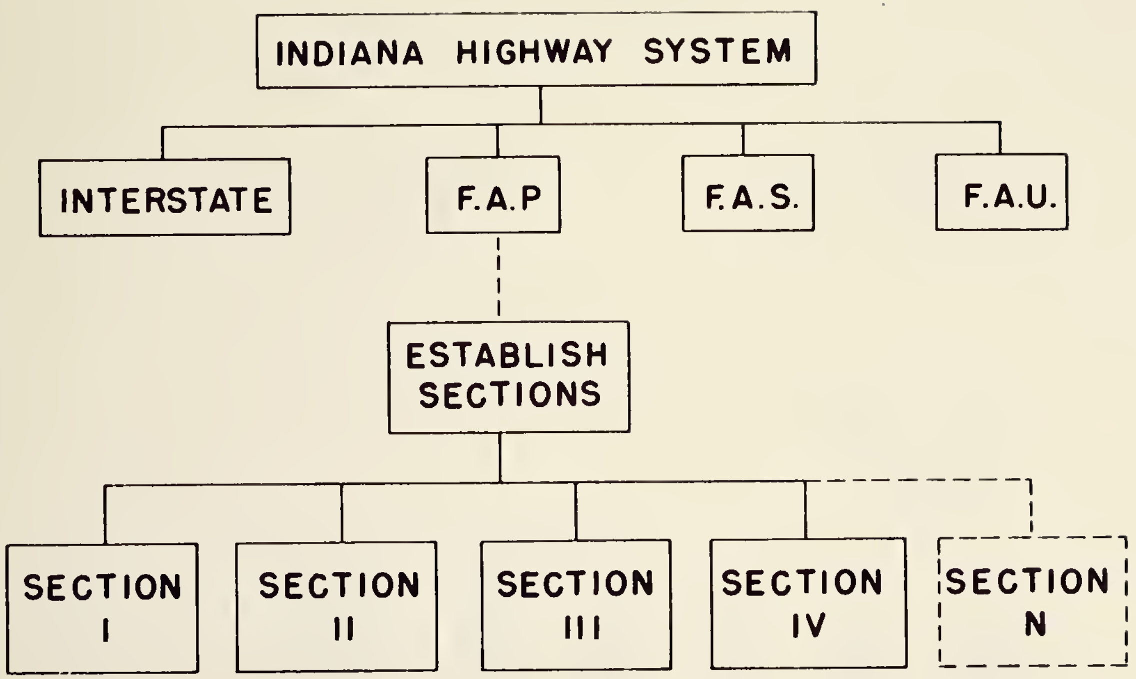


FIG. 3 ESTABLISH SECTIONS BY SYSTEM CLASSIFICATION

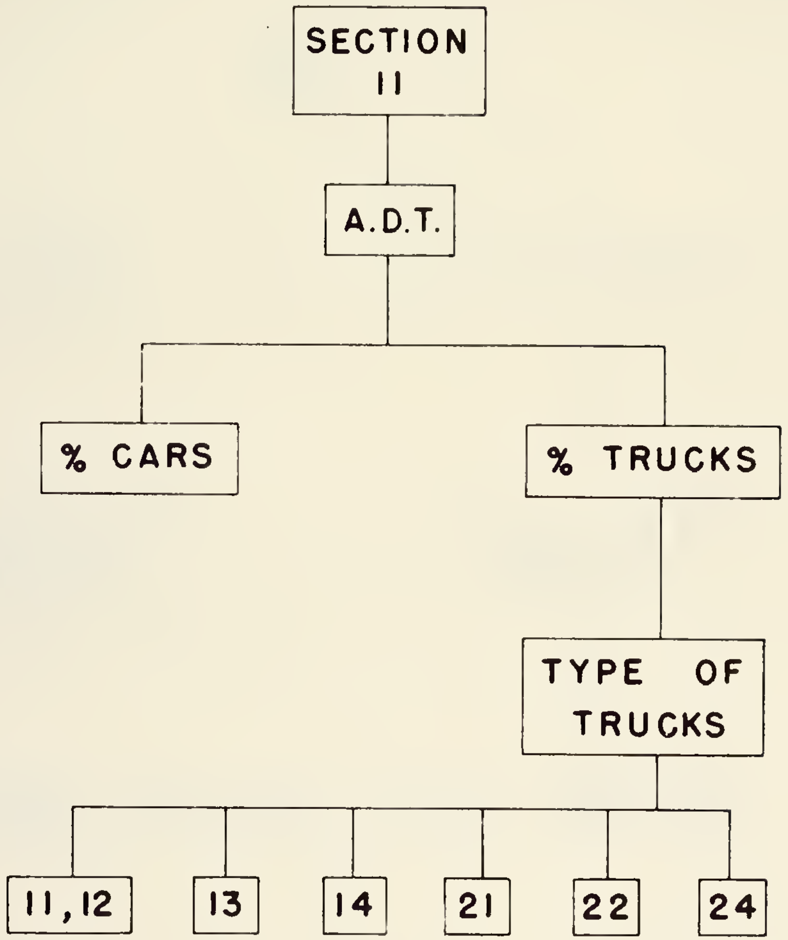


FIG. 4 INFORMATION ESTABLISHED FOR EACH SECTION

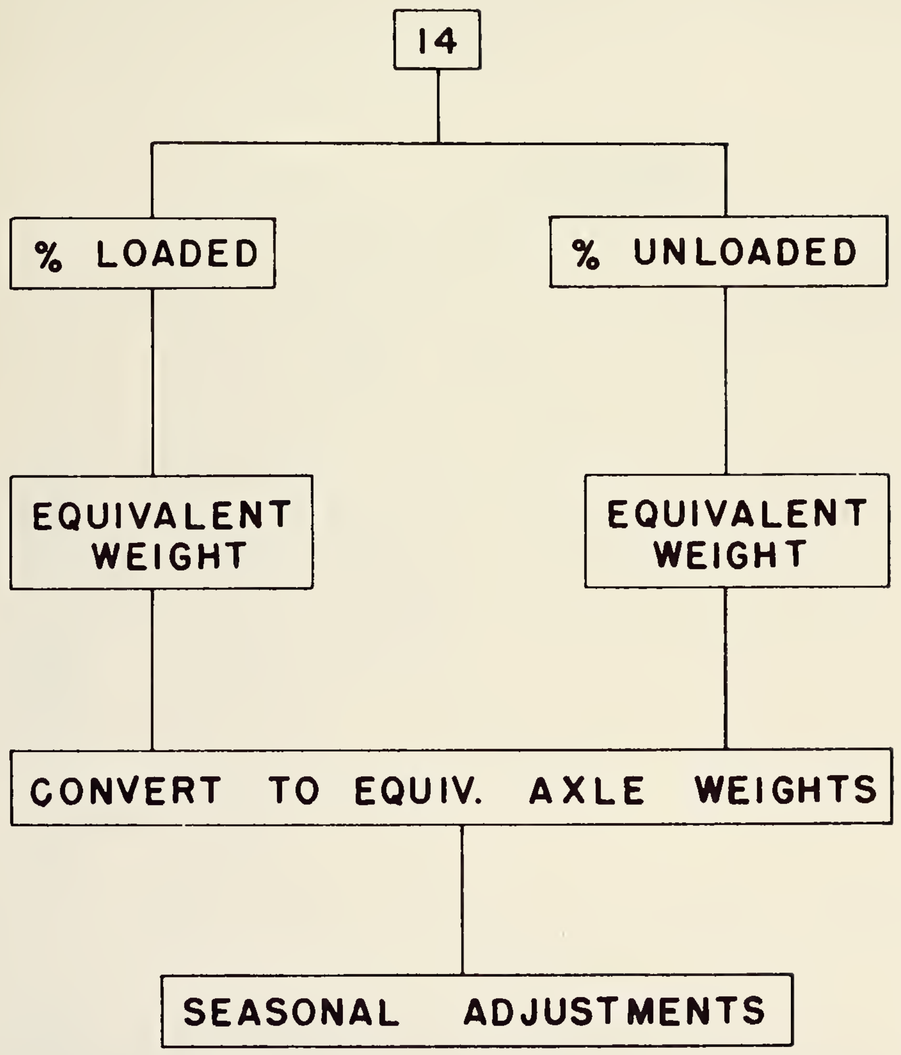


FIG. 5 INFORMATION ESTABLISHED FOR EACH TRUCK TYPE

TRUCK TYPE	STATION						
	1	2	3	4	5	6	7
1	$\bar{X}_{11}$ V_{11}	$\bar{X}_{12}$ V_{12}	$\bar{X}_{13}$ V_{13}	– –	– –	– –	$\bar{X}_{17}$ V_{17}
2	$\bar{X}_{21}$ V_{21}	$\bar{X}_{22}$ V_{22}	– –	– –	– –	– –	$\bar{X}_{27}$ V_{27}
3	$\bar{X}_{31}$ V_{31}	– –	– –	– –	– –	– –	$\bar{X}_{37}$ V_{37}

FIG. 6 · ANALYSIS OF VARIANCE — TRUCK TYPE VERSUS STATION

5. If similarity is not established but homogenity is present or can be achieved by transformation, a one way analysis of variance is performed to evaluate similar station characteristic by truck types. An evaluation of the specific truck types which are similar over all stations must be made. If these are generally the lighter trucks, it would be wrong to assume similarity.
6. Failing to achieve homogenity of variance, one can perform a cell by cell comparison of each truck type by each station. By use of the T Test, the mean equivalent axle weights for each given truck type can be tested for significant differences. See Figure 7.
7. The results of step 6 can be illustrated in Figure 8, which indicates the stations that have non-significant differences for each truck type. The test shows that stations four and five are similar for all truck types and stations two and three are similar except for truck type three. The decision as to continuance of stations two and three might depend upon the weight of truck type three or the expected frequency of this vehicle at both stations.

Conclusion

Once stations are found to be statistically similar, new sections or stations would be added in the following year to replace all but one of these stations. The stations replaced are slave stations. A

$\bar{X}_1$ VS $\bar{X}_2$	$\bar{X}_1$ VS $\bar{X}_3$	$\bar{X}_1$ VS $\bar{X}_4$	$\bar{X}_1$ VS $\bar{X}_5$	$\bar{X}_1$ VS $\bar{X}_6$	$\bar{X}_1$ VS $\bar{X}_7$
$\bar{X}_2$ VS $\bar{X}_3$	$\bar{X}_2$ VS $\bar{X}_4$	$\bar{X}_2$ VS $\bar{X}_5$	$\bar{X}_2$ VS $\bar{X}_6$	$\bar{X}_2$ VS $\bar{X}_7$	
$\bar{X}_3$ VS $\bar{X}_4$	$\bar{X}_3$ VS $\bar{X}_5$	$\bar{X}_3$ VS $\bar{X}_6$	$\bar{X}_3$ VS $\bar{X}_7$		
$\bar{X}_4$ VS $\bar{X}_5$	$\bar{X}_4$ VS $\bar{X}_6$	$\bar{X}_4$ VS $\bar{X}_7$			
$\bar{X}_5$ VS $\bar{X}_6$	$\bar{X}_5$ VS $\bar{X}_7$				
$\bar{X}_6$ VS $\bar{X}_7$					

$$T = \frac{\bar{X}_i - \bar{X}_j}{\sqrt{\frac{V_i^2}{N_i} + \frac{V_j^2}{N_j}}}$$

FIG. 7 SIGNIFICANCE TEST FOR DIFFERENCES BETWEEN PAIRS OF MEANS

(EQUIVALENT AXLE WEIGHT FOR GIVEN TRUCK TYPE)

TRUCK TYPE	NON-SIGNIFICANT DIFFERENCES	SIGNIFICANT DIFFERENCES
1	1-2-3-4-5-6-7	
2	2-3, 4-5, 6-7	1
3	3-4-5, 2-7	1,6
4	4-5-6-7, 2-3	1
5	1-2-3-4-5	6,7

FIG. 8 ANALYSIS OF MEANS TEST BY STATION

classification count will be performed at each slave station each year in order to establish the percentage of each truck type in the traffic stream. The mean 18 kip equivalent axle load per truck type will be established by the continuing master station. To accomplish the statistical testing proposed, computer programs were written in Fortran IV for the IBM 7090. The details of the statistical evaluation to determine station similarities by stations or by truck type are presented in a Purdue University Joint Highway Research Project Report No. 8, June 1965, "Procedural Guide for Estimating Axle Loadings on a Statewide Basis". Copies are available at the cost of reproduction (about $5).

Over a period of several years,all sections of the state highway system can be tested for similarities. The end results might be a slightly larger number of annual loadometer stations and certainly a large number of classification counts would be required, but a statistically sound estimate of axle loadings on all state highways of Indiana would then be available at a reasonable cost.

List of References

1. American Trucking Trends 1964, American Trucking Association, Washington, D.C., 1964.
2. Automobile Facts and Figures, Automobile Manufacturers Association, Detroit, Michigan, 1965.
3. Motor Truck Facts 1964, Automobile Manufacturers Association, Detroit, Michigan, 1964.
4. Instructional Memorandum 50-2-64, "1964 Truck Weight Study", Bureau of Public Roads, U. S. Department of Commerce, Washington, D.C.